PERFORMANCE ANALYSIS OF FREE SPACE OPTICS (FSO) UNDER TURBULENT CONDITIONS USING DENSE WAVELENGTH DIVISION MULTIPLEXING (DWDM)

(The synopsis submitted towards the partial fulfilment of requirement for the award of degree of)

Ph.D

In

ELECTRONICS AND COMMUNICATION ENGINEERING

Under the guidance of

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Candidate's Declaration

I hereby declare that the thesis entitled "**Performance Analysis of Free Space Optics (FSO) under Turbulent Conditions using Dense Wavelength Division Multiplexing (DWDM)**" submitted by me in partial fulfilment of requirements for the award of degree of PhD (Electronics and Communication) to Desh Bhagat University is a record of my own work carried out under the supervision and guidance of **Dr. Gurinder Kaur Sodhi,** Assistant Professor, Department of Electronics and Communication Engineering, Deshbhagat University Mandi Gobindgarh.

To the best of my knowledge this thesis has not been submitted to earlier to any other University or Institute for the award of any degree.

Date: **Ifat Rasheed**

Place: DBU, Mandi Gobindgarh **Roll no. 20380179001**

This is to certify that the above statement made by the candidate is correct to the best of my knowledge .

Signature of supervisor
Dr. Gurinder Kaur Sodhi
Department of ECE,
Deshbhagat University, Gobindgarh

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Chapter 1

Introduction

Wireless communication has bought a revolution on account of increasing demand for high data rate communication devices. High speed networks are highly required which focus on increasing the transmission capacity and coverage area. A wide range of wireless communication standards have saturated the Radio Frequency (RF) spectrum; therefore an alternative to RF communication is a necessity of modern communication network. In this backdrop the Free Space Optical (FSO) communication is evolving as an alternative to RF. It is rapidly growing technology in the field of wireless communication. Free Space Optical (FSO) communication is one of the most promising technology for providing transmission rates that are very higher than transmission rates by Radio Frequency (RF) technology besides providing high quality factor (Q-factor) which is an important parameter for the design of communication receivers.

FSO, also called as optical wireless communication or laser communication, has combined properties of wireless and optical fiber. The medium of transmission in FSO is air/space (unlike fiber optics which uses glass fiber). Therefore, the light pulses instead of transmitting through glass of fiber are transmitted through atmosphere. FSO is an optical communication technique in which line of sight is used to meet the demand of high bandwidth over short distances. An optical modulated data is transmitted by FSO using a visible or IR band of frequencies. Use of optical carrier allows higher bandwidth. Interception of the optical signal is very difficult, which results in high security in the communication. Higher bandwidth, high security, ease of deployment and less power consumption compared to Radio Frequency (RF) transmission makes FSO more suitable for the high-speed broadband networks.

Free space optical communication is cost efficient, flexible, simple and have easy installation. Since the transmission medium used in FSO is atmosphere, hence, digging/making of channels for fiber laying is not required, this helps in both the time and cost efficient nature of FSO.

However the use of atmosphere as a transmission medium in FSO limits its performance due to the atmospheric turbulences that limit this technique to short range distances. The atmospheric turbulences include rain, dust, fog, snow, smoke and scintillations. These atmospheric turbulences deteriorate the performance of FSO link. Though FSO has tremendous potential to compete with existing communication technologies, the growth of FSO technology is hampered by various parameters like building motion, atmospheric losses due to weather and atmospheric turbulence. These parameters interrupt the communication. Atmospheric losses due to bad weather condition can be compensated by operating FSO at a higher wavelength. Atmospheric turbulence causes random fluctuation in the intensity and phase of the received signal at the receiver. This directly affects the quality of received signal and reduces the deployable link distance. It can occur even in clear weather condition for any duration of day and night.

To remove these shortcomings, some techniques like diversity, aperture averaging and the use of optical amplifiers for amplification of signal will be studied in this work.

Optical amplifiers can be deployed for optical amplification of signals and these optical amplifiers include Raman, SOA, or Erbium Dopped Fiber Amplifier (EDFA). Among these, EDFA is the most commonly used optical amplifier and due to its high gain and bandwidth it is used for multiple wavelength amplification or in other words it can be deployed in wavelength division multiplexing (WDM) networks easily.

Working of FSO: Free space optical communication uses two trans receivers at both the ends for providing full duplex communication. The network traffic is first converted into the pulses of invisible light representing binary 1's and 0's. Infrared waves are generated by LED and Laser diodes at a transmitter side that act as a carrier for data transmission.

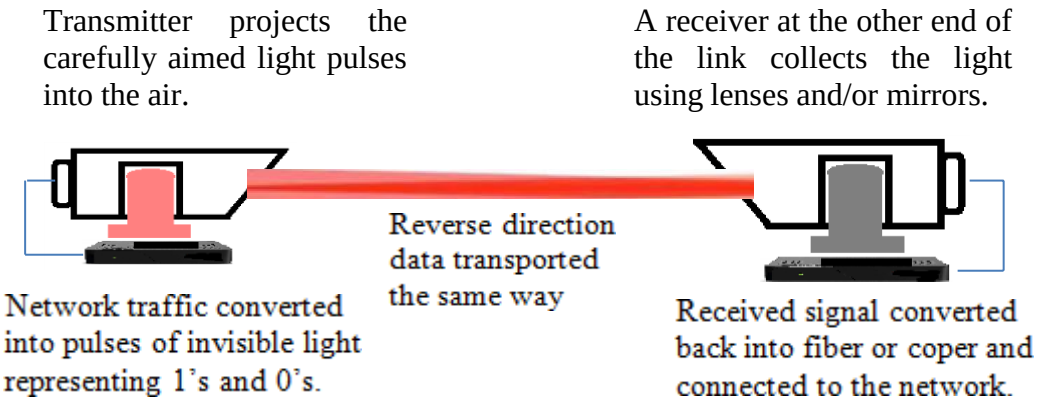
Transmitter projects the carefully aimed light pulses into the air.
A receiver at the other end of the link collects the light using lenses and/or mirrors.
Reverse direction data transported the same way
Network traffic converted into pulses of invisible light representing 1's and 0's.
Received signal converted back into fiber or coper and connected to the network.

Fig: 1.1 Working of FSO: An Overview

There are three main functional elements in FSO - transmitter, atmospheric channel and receiver. At the transmitter, the modulator modulates the information signal and converts the electrical signal to optical signal using the optical source (LED or laser). The most commonly used modulation method is Intensity Modulation. The radiation of LED or laser is aligned by telescope to a collimated beam that is propagated towards the receiver.

The transmitted signal propagates through the atmosphere where it attenuates due to absorption, scattering and turbulence. The signal attenuate due to harsh weather conditions like rain, snow, haze, fog, turbulence.

At the receiver end, the telescope receives the incoming radiated signal and directs the signal towards optical filter. The optical filter allows passing only the wavelength of the signal and blocks other radiations from the atmosphere. The detector converts the optical signal back to the electrical signal which is directed to the amplifier to amplify the signal. The receiver processing circuits include decision device and clock recovery circuit which recovers the information at the receiver end.

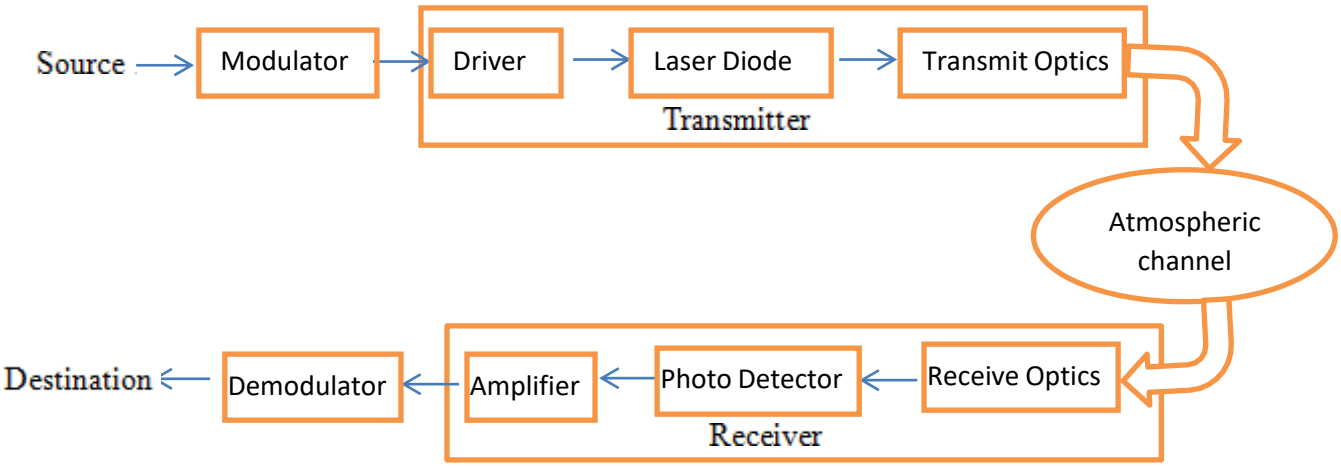

Fig: 1.2 Block diagram of a terrestrial FSO system

The components of block diagram of FSO communication system are explained as follows:

1. **Transmitter:** The transmitter is primarily concerned with the modulation of the source data. The modulation is done by using optical signal as a carrier and intensity modulation is the most common type of modulation used. Intensity modulation refers to the modulation of source data where irradiance of optical signal is used as a carrier wave. This modulation can be performed either directly by an external modulator (like symmetric Mechzender Interferometer) or by directly changing driving current of optical source in response to the transmitter information.
2. **Atmospheric channel:** An atmospheric channel is Free Space composed of gases, aerosols and suspended tiny particles.
3. **Receiver:** Receiver retrieves the source data from incident optical field. The components of receiver are receiver telescope, optical band pass filter, and photo detector and decision circuit / post demodulation process.

Usage of FSO:

- FSO technique does not require any RF license from any of the agencies, as the signal is optically modulated.
- There is no interference of the signal by the radio frequencies; hence, fewer disruption to the information flow.
- FSO being an easily installing technique is used for interconnecting LAN segments to enable communication.
- Digging of streets and rooftop installation is not needed.
- No security upgrades are required as there is a line of sight based communication.
- The data rates provided by FSO channels is very high as compared to that of the RF links and it operates on the frequency range of up to 3THZ.
- FSO do not require any license from any agency, hence, it can be used for communication by wireless service providers.

- In case of a failure transmission through a fiber link, FSO can be used in providing a backup link.
- FSO being a secure and undetectable technique can connect large areas safely with minimum planning.

Chapter 2

Extracts of Literature Search

Introduction

A literature review is a survey of scholarly sources on a specific topic. It provides an overview of current knowledge, allowing you to identify relevant theories, methods, and gaps in the existing research. An exhaustive literature review has been carried out by the researcher in the context of the present work . Some of them are briefly presented below:

Literature Review

An exhaustive literature review has been carried out by the researcher in the context of the present work . Some of them are briefly presented below :

Sooraj Parkash et al in [1] have discussed about about the demonstration of a DWDM based FSO communication system working on 8 channels with channel spacing of 0.8 nm and each channel having a data rate of 5 GB/s such that the overall data rate of a system is 40 GB/s . The range of FSO link is 4km. The study also concludes that bit error rate increases sharply when the range of FSO is increased beyond 4km.

Simranjit Singh & R. S. Kaler in [2] presents the design of novel flat-gain amplifier using a hybrid combination of Er-Yb co-doped amplifier (EYDWA) and a semiconductor optical amplifier (SOA) for 100*10-Gb/s dense wavelength division multiplexed system at 0.2 nm interval as a result of which a flat gain of >14 dB is obtained across the effective bandwidth with a gain variation of 0.75 db without using any gain clamping techniques. This proposed hybrid amplifier reduce the gain of DRAEDFA HOA from approximately 2.01 to 1.15 dB efficiently. Hence, resulted in improved performance in terms of cost, gain flatness etc.

Xiaojie Guo & Chester Shu in [3]. backward Raman pump has been used to reduce the cross gain modulation for multi wavelength amplification in a fiber optical amplifier (FOPA) and a comparison is made between the performances of two wavelength amplifications of FOPA's with and without Raman pump under the condition of identical unsaturated gains. This resulted in the reduction of cross gain modulation of one channel due to the presence of other WDM channel having high input power as compared to the conventional FOPA having

identical unsaturated gain. Hence, a power penalty of 6.3 dB is obtained for a 10-Gb/s RZ-OOK signal at a BER of 10-8.

Mahmoud Jazayerifar, et al in [4] have derived the analytical expressions for the performance of long-haul DWDM communication system employing in-line phase sensitive fiber optic parametric amplifiers(FOPA).The errors due to transmission fibers and FOPA's are considered and the model is then verified using simulations. The performance of FOPA is compared with EDFA and it is observed that the broad band long haul DWDM transmission system based on FOPA's could be feasible.

Hardeep Singh & Sukhwinder Singh [5] have investigated the performance of hybrid amplifiers- RAMAN-EDFA, RAMAN-SOA,EDFA-SOA in WDM systems having 120 channels, with each channel having data rate of 10 Gb/s and reduced channel spacing of 50 GHZ. The performance has been compared by varying the different parameters like fiber length, Q factor, BER etc and it is observed that RAMANEDFA is the best alternative to RAMAN-SOA & EDFA-SOA in high capacity WDM system with reduced channel spacing.

Xiaojie Guo & Chester Shu in [6] investigated both theoretically and experimentally the reduction of four wave mixing crosstalk in multi-wavelength amplification in backward pumped Raman assisted fiber optical parametric amplifier (FOPA).A suppression of more than 7 dB in FWM crosstalk initiated from both degenerate –FWM and non degenerate –FWM has been obtained. The authors also described the effects of signal channel number and the powers of the parametric pump and the Raman pump on the FWM crosstalk.

Simranjit & R. S. Kaler in [7] have provided the demonstration of an efficient gain-flattened L-band optical amplifier using a hybrid configuration of distributed Raman amplifier(DRA) and an erbium-doped fiber amplifier (EDFA) for 160*10 Gb/s dense wavelength division multiplexed system at 25-GHZ interval. A flat gain of >10dB is obtained with an input signal power of 3 mW across the frequency range from 187 to 190.975 THZ having a gain variation of <4.5 dB without the use of any gain flattening technique.

Thomas Torounidis in [8] have demonstrates experimentally the performance of fiber optical parametric amplifier(FOPA) in WDM applications for the first time. The authors investigate both 3 * 10 GB/s and a commercial 7*2.5 Gb/s WDM system with the parametric amplifier. This paper also presents the performance in terms of power penalty and gain versus input-output signal power.

M.F.C Stephens in [9] ahve demonstrate experimentally a Raman Assisted Fiber Optical Parametric Amplifier(RA-FOPA) having 20 dB net gain using WDM signals .They also reported amplification of 10*58 Gb/s 100 GHZ-spaced QPSK signals and showed that the gain improvement of upto 5 dB can be obtained for the RA-FOPA by properly tuning parametric pump and compared with the combined individual contribution from the parametric and Raman pumps. Also, RA-FOPA is compared with a conventional FOPA having same gain and it was observed that the four wave mixing crosstalk is suppressed upto 5.8±0.4 dB using RA-FOPA.

E. Ciaramella, et al in [10] have provided the highest transmission rate of 32*40 Gbps that is four times greater than the results obtained in the previous studies. The system is also upgraded to its highest capacity of 1.28 Terabit/s which was the highest capacity obtained than the capacity obtained in the previous results.

Vishal Sharma and Gurimandeep Kaur in [11] have analysed the architecture of multipath fading resistant fading communication system using OFDM multicarrier scheme along with OTSB (optical tandem side band) and OSSB (optical single side band) schemes. This system provided a great flexibility in the atmospheric turbulences like fog, haze etc that affect the performance of FSO communication system and hence resulted in increase in the transmission rate. The study also reveals that due to the large immunity against fading, the performance of OSSB is better than OTSB at high data rates.

Soorajparkash et al in [12] have used a WDM-PON(wavelength division multiplexing-passive optical network) based FTTH (fiber to the home) is designed aiming to offer the high data rates (GB/S) to the residential subscribers and the data rate transmission was upgraded to 20*32 GB/S(640 GB/S).Also, The appreciable values of bit error rate are obtained.

G. NYKOLAK et al in [13] have obtained the data rate of 40Gb/s over a free space optical link of 4.4 km in a DWDM based FSO communication system. The designed system works on 16 separate channels having 200Ghz of channel spacing between them.

Jasvir Singh et al in [14] have used a WDM based FSO communication system is developed. The system supports 32 channels, each having a data rate of 40 Gbps over a range of 1km of FSO link using NRZ and RZ line coding. The results also showed that NRZ performs better than RZ line coding technique.

Amninder Kaur et al in [15] have included review of free space optics. In this paper, the authors have discussed FSO and its need, improvements that can be made in FSO technique

and the use of FSO technology in DWDM systems. The various parameters that limit the performance of FSO system like atmospheric turbulences including scintillation losses, fog attenuation etc have also been discussed.

Pooja Kumari & Rajeev Thakur in [16] have proposed the use of hybrid amplifiers in FSO system. FSO technique has been discussed in detail. Different types of hybrid amplifiers, their features and comparison are discussed. It has been observed that the Raman –EDFA.

S. Guizani et al in [17] have incorporated a post-compensation technique to optically compensate the chromatic dispersion in fiber. A temporal effect is used by a fiber having a range beyond 40G/bits.

Rajani et al in [18] have used various compensation techniques including pre-compensation, post- compensation and symmetric compensation are used by using standard mode fiber and dispersion compensated fiber and a comparative analysis between these compensation techniques is made at data rate of 10/15 Gbps at different modulation formats and different optical power levels. It was observed that post and symmetric compensated systems showed better results.

Mohammad Ali Khalighi and Murat Uysal in [19] have given a detailed theoretical information about FSO channel models and transmitter/receiver structure have been discussed by the authors. The limitations of FSO system and algorithmic level system designs have been discussed to overcome these limitations.

Alla Abbas Khadir, in [20] have used a simulation of various systems using different techniques by optisystem program is discussed. The main aim of authors is to make the use of optisystem clear to the ones who are not aware of it. Various simulation models like DWDM system, DCF system, DBM system have been designed and simulated by the author using optisystem program.

Ankita Shivhare, et al in [21] have demonstrated the behaviour of optical wireless communication system by varying the aperture of FSO link. The simulation results indicate that the variations in FSO aperture result in improving distance of FSO.

Vishal Sharma et al in [22] have demonstrated CDMA-FSO coherent detection system with 10 Gbps data rate and reasonable SNR under the effect of atmospheric turbulences like rain, snow etc.

Shao Hao Wang et al in [23] have investigated the gain of Raman assisted fiber optical amplifier. Also, a normalised phase-matched model is proposed to achieve the performance of peak value of gain of RA-FOPAs that operate in low magnitude region.

R. S. Kaler, et al in [24] have demonstrated the compensation schemes (pre-,post-,symmetric) in a system with 10Gbps data rate &NRZ modulation by using single mode fiber & dispersion compensated fiber to achieve transmission at high data rates. It is observed that symmetric compensation is superior followed by post-,& pre compensation schemes.

Manpreet Kaur and Himali Sarangal in [25], compensation techniques have been used to investigate 40 Gbps WDM system by using dispersion compensated fiber. Also, comparative analysis is made at the receiving side with respect to variation in different parameters.

Manpreet Kaur and Himali Sarangal in [27] have compensated the dispersion of a fiber by using dispersion compensated fiber at 20 Gbps. Three compensation schemes(pre- ,post- & symmetric-) have been used and a comparative analysis between these schemes is made.

Inferences Drawn Out of Literature Search

A wide range of wireless communication standards have saturated the Radio Frequency (RF) spectrum; therefore an alternative to RF communication is the Free Space Optical (FSO) communication which is evolving as an alternative to RF. It is the most promising technology for providing transmission rates that are very higher than transmission rates by Radio Frequency (RF) technology besides providing high quality factor (Q-factor) which is an important parameter for the design of communication receivers.

From the literature review following observations are revealed which form the inferences:

- Free space optical links are highly affected by atmospheric degrading effects like rain, snow, fog turbulence etc. which reduces the effective line of sight link length.
- Tuning of hybrid optical amplifiers to support FSO signal.

Scope for Present Work:

- FSO communication is the promising technology for providing maximum data rates with minimum errors.
- Use of FSO a low cost technique whereas the use of optical fibers is a very costly technique.
- DWDM allows multiplexing of signals that can provide data rates up to 100 Gbps. Therefore, transmission at maximum data rates is possible.

- DWDM leads to interference and losses due to many reasons like less channel spacing etc.
- Compensation techniques/schemes are used to combat the losses that occur due to minimum/low channel spacing or that are incurred in the atmospheric channel. *Pre-, post* and *symmetric compensation* techniques/schemes are used to deliver the data at reasonable BER values.

S.No	Author	Title	Year of publication	Literature extract
1.	Abu Jahid, Mohammed H. Alsharif and Trevor J. Hall	A Contemporary Survey on Free Space Optical Communication: Potential, Technical Challenges, Recent Advances and Research Direction	2020	In this paper, the authors have discussed FSO and its need, improvements that can be made in FSO technique and the use of FSO technology in DWDM systems. The various parameters that limit the performance of FSO system like atmospheric turbulences including scintillation losses, fog attenuation etc have also been discussed.
2.	Sumant Malik and Prasant Sahu	Performance Analysis of Free Space Optical Communication System Using Different Modulation Schemes over Weak to Strong Atmospheric Turbulence Channels	2020	In this paper, various compensation techniques including pre-compensation, post- compensation and symmetric compensation are used by using standard mode fiber and dispersion compensated fiber and a comparative analysis between these compensation techniques is made at data rate of 10/15 Gbps at different modulation formats and different optical power levels.
3.	Abdulgani A.IbrahimSerdar ÖzgürAtaEylemErdoğanLütfiyeDurak-Ata	Performance analysis of free space optical communication systems over imprecise Málaga fading channels	2019	They have obtained the data rate of 40Gb/s over a free space optical link of 4.4 km in a DWDM based FSO communication system. The designed system works on 16 separate channels having 200Ghz of channel spacing between them.
4.	Arockia Bazil Raj,Arun K. Majumder	Historical perspective of free space optical communications: from the early dates to today's developments	2019	This paper has discussed the history of rise and growth/development of the free space optical communication

				from the very beginning.
5.	Manish Sahu, Kappala Vinod Kiran, Santos Kumar Das	FSO Link Performance Analysis with Different Modulation Techniques under Atmospheric Turbulence	2018	The authors of this paper analysed the architecture of multipath fading resistant fading communication system using OFDM multicarrier scheme along with OTSB (optical tandem side band) and OSSB (optical single side band) schemes. This system provided a great flexibility in the atmospheric turbulences like fog, haze etc that affect the performance of FSO communication system and hence resulted in increase in the transmission rate. The study also reveals that due to the large immunity against fading, the performance of OSSB is better than OTSB at high data rates.
6.	Pooja Kumari & Rajeev Thakur	BER Evaluation of FSO Link with Hybrid Amplifier for Different Duty Cycles of RZ Pulse in Different Conditions of Rainfall	2017	They have proposed the use of hybrid amplifiers in FSO system. FSO technique has been discussed in detail. Different types of hybrid amplifiers, their features and comparison are discussed. It has been observed that the Raman –EDFA.
7.	Sooraj Parkash et al	Performance Investigation of 40 GB/s DWDM over Free Space Optical Communication System Using RZ Modulation Format	2016	Demonstration of a DWDM based FSO communication system working on 8 channels with channel spacing of 0.8 nm and each channel having a data rate of 5 GB/s such that the overall data rate of a system is 40 GB/s. The range of FSO link is 4km. The study also concludes that bit error rate increases sharply when the

				range of FSO is increased beyond 4km.
8.	M.F.C Stephens	Suppression of WDM four-wave mixing crosstalk in fibre optic parametric amplifier using Raman-assisted pumping	2015	The author in this paper demonstrated experimentally a Raman Assisted Fiber Optical Parametric Amplifier(RA-FOPA) having 20 dB net gain using WDM signals .They also reported amplification of 10*58 Gb/s 100 GHZ-spaced QPSK signals and showed that the gain improvement of upto 5 dB can be obtained for the RA-FOPA by properly tuning parametric pump and compared with the combined individual contribution from the parametric and Raman pumps.
9.	E. Ciaramella, Y. Arimoto, G. Contestabile, M. Presi,A.D'Errico, V.GuarinoM. Matsumoto	1.28 Terabit/s (32×40 Gbit/s) WDM transmission over a double-pass free space optical link	2015	They have provided the highest transmission rate of 32*40 Gbps that is four times greater than the results obtained in the previous studies. The system is also upgraded to its highest capacity of 1.28 Terabit/s which was the highest capacity obtained than the capacity obtained in the previous results.
10	SOORAJPARKASH,ANURAG SHARMA, MANOJ KUMAR& HARSUKHPREET SINGH	Performance Enhancement of WDM-PON FTTH Network by Using Decision Feedback and Feed forward Equalizations	2015	In this paper, a WDM-PON(wavelength division multiplexing- passive optical network) based FTTH (fiber to the home) is designed aiming to offer the high data rates (GB/S) to the residential subscribers and the data rate transmission was upgraded to 20*32 GB/S(640 GB/S).Also, The appreciable values of bit error rate are obtained.

11	Xiaojie Guo & Chester Shu	Tailoring of saturation in fiber optical parametric amplifier by SBS-induced nonlinear phase	2014	Raman pump has been used to reduce the cross gain modulation for multi wavelength amplification in a fiber optical amplifier (FOPA) and a comparison is made between the performances of two wavelength amplifications of FOPA's with and without Raman pump under the condition of identical unsaturated gains.
12	Simranjit Singh & R. S. Kaler	Power transient and its control in Raman-erbium doped fiber amplifier hybrid optical amplifier subject to multi-channel bursty traffic	2014	This research paper presents the design of novel flat-gain amplifier using a hybrid combination of Er-Yb co-doped amplifier (EYDWA) and a semiconductor optical amplifier (SOA) for 100*10-Gb/s dense wavelength division multiplexed system at 0.2 nm interval as a result of which a flat gain of >14 dB is obtained across the effective bandwidth with a gain variation of 0.75 db without using any gain clamping techniques.
13	Hardeep Singh & Sukhwinder Singh	Performance Analysis of Hybrid Optical Amplifiers in 120 x 10 Gbps WDM Optical Network with Channel Spacing of 50 GHz	2014	They have investigated the performance of hybrid amplifiers- RAMAN-EDFA, RAMAN-SOA,EDFA-SOA in WDM systems having 120 channels, with each channel having data rate of 10 Gb/s and reduced channel spacing of 50 GHZ. The performance has been compared by varying the different parameters like fiber length, Q factor, BER etc and it is observed that RAMANEDFA is the best alternative to RAMAN-SOA &

				EDFA-SOA in high capacity WDM system with reduced channel spacing.
14	Xiaojie Guo & Chester Shu	Control of Saturation Characteristics in a Fiber Optical Parametric Amplifier by Raman Amplification	2014	They have investigated the reduction of four wave mixing crosstalk in multi-wavelength amplification in backward pumped Raman assisted fiber optical parametric amplifier (FOPA).A suppression of more than 7 dB in FWM crosstalk initiated from both degenerate –FWM and non degenerate –FWM has been obtained.
15	Jasvir Singh, Pushpa Gilawat & Balkrishna Shah	Performance evaluation of 4 × 12 Gbps DWDM system using CO-OFDM detection scheme with and without dispersionn compensation scheme Performance evaluation of 4 × 12 Gbps DWDM system using CO-OFDM detection scheme with and without dispersion compensation scheme	2014	They have used a WDM based FSO communication system is developed. The system supports 32 channels, each having a data rate of 40 Gbps over a range of 1km of FSO link using NRZ and RZ line coding. The results also showed that NRZ performs better than RZ line coding technique.
16	Amninder Kaur, Sukhbir Singh and Rajeev Thakur	Review Paper: Free Space Optics	2014	In this paper, the authors have discussed FSO and its need, improvements that can be made in FSO technique and the use of FSO technology in DWDM systems. The various parameters that limit the performance of FSO system like atmospheric turbulences including scintillation losses, fog attenuation etc have also been discussed.
17	Mahmoud Jazayerifar, Stefan Warm, Robert Elschner, Dimitar	Performance Evaluation of DWDM Communication Systems With Fiber Optical Parametric Amplifiers	2013	They have derived the analytical expressions for the performance of long-haul DWDM communication system employing in-line

	Kroushkov, Isaac Sackey, Christian Meuer, Colja Schubert, and Klaus Petermann			phase sensitive fiber optic parametric amplifiers (FOPA).The errors due to transmission fibers and FOPA's are considered and the model is then verified using simulations. The performance of FOPA is compared with EDFA and it is observed that the broad band long haul DWDM transmission system based on FOPA's could be feasible.
18	Simranjit & R. S. Kaler	Hybrid optical amplifiers for 64 × 10 Gb ps dense wavelength division multiplexed system	2013	They have provided the demonstration of an efficient gain-flattened L-band optical amplifier using a hybrid configuration of distributed Raman amplifier(DRA) and an erbium-doped fiber amplifier (EDFA) for 160*10 Gb/s dense wavelength division multiplexed system at 25-GHZ interval. A flat gain of >10dB is obtained with an input signal power of 3 mW across the frequency range from 187 to 190.975 THZ having a gain variation of <4.5 dB without the use of any gain flattening technique.

Chapter 3

Problem Statement and Objectives

Problem Statement

- To evaluate and design suitable FSO-DWDM link using compensation techniques to enhance link reliability.
- To evaluate performance of FSO-DWDM link for reduced channel spacing using different optical modulation techniques.
- To optimise FSO-DWDM link so that desired link characteristics can be maintained for data rates higher than 10Gbps.
- To design FSO-DWDM link that can support multiple users in excess of 30 in number for decreased values of channel spacing.

Objectives

The main objective of this work is to analyse the performance of FSO system under turbulent condition such as fog, mist, clouds, rain, dust, etc. using DWDM. Accordingly the following objectives has been setup and addressed.

1. To evaluate various parameters for FSO system and finalize a technique to mitigate suitable atmospheric turbulence effect.
2. Analyse and development for wavelength (γ) diversity based FSO system to attain under moderate and suitable turbulence conditions.
3. To compare the obtained results with the existing works (research) to identify an appropriate channel model that represents all turbulence condition and achieves significant performance improvement with DWDM.
4. To evaluate the performance of the developed system using parameters like bit error rate (BER) and signal to noise ratio (SNR).

Proposed Work

- To design FSO-DWDM system which can deliver reasonable performance over long distances.
- To investigate the effect of pre, post and symmetric compensation techniques in improving the link reliability.
- To investigate the performance of FSO link using DWDM technique.

Chapter 4

Research Methodology

The proposed work will be dealt with following research methodology;

1) The entire work will be carried out through the simulation software-Optisystem (version 7.0).
2) The primary aspect of the methodology includes the process of simulation.
3) The main aim of simulation will be to design different DWDM systems with FSO transmission link varying in number of channels and to apply the use of hybrid amplifiers and compensation techniques for increasing the transmission distance.
4) The number of channels used will vary as 30, 40, 50 and 60.
5) The transmission distance will be from 1 km to 5 km.
6) The proposed compensation techniques will be pre-compensation, post-compensation and symmetric compensation.
7) In addition to that a hybrid combination of EDFA and SOA amplifiers will also be used in a DWDM system for the evaluation of the performance of system.
8) The study will also focus on the variation of various parameters including attenuation, channel spacing, data rates, modulation format with respect to the change in FSO length and observing the effect on performance of the system.

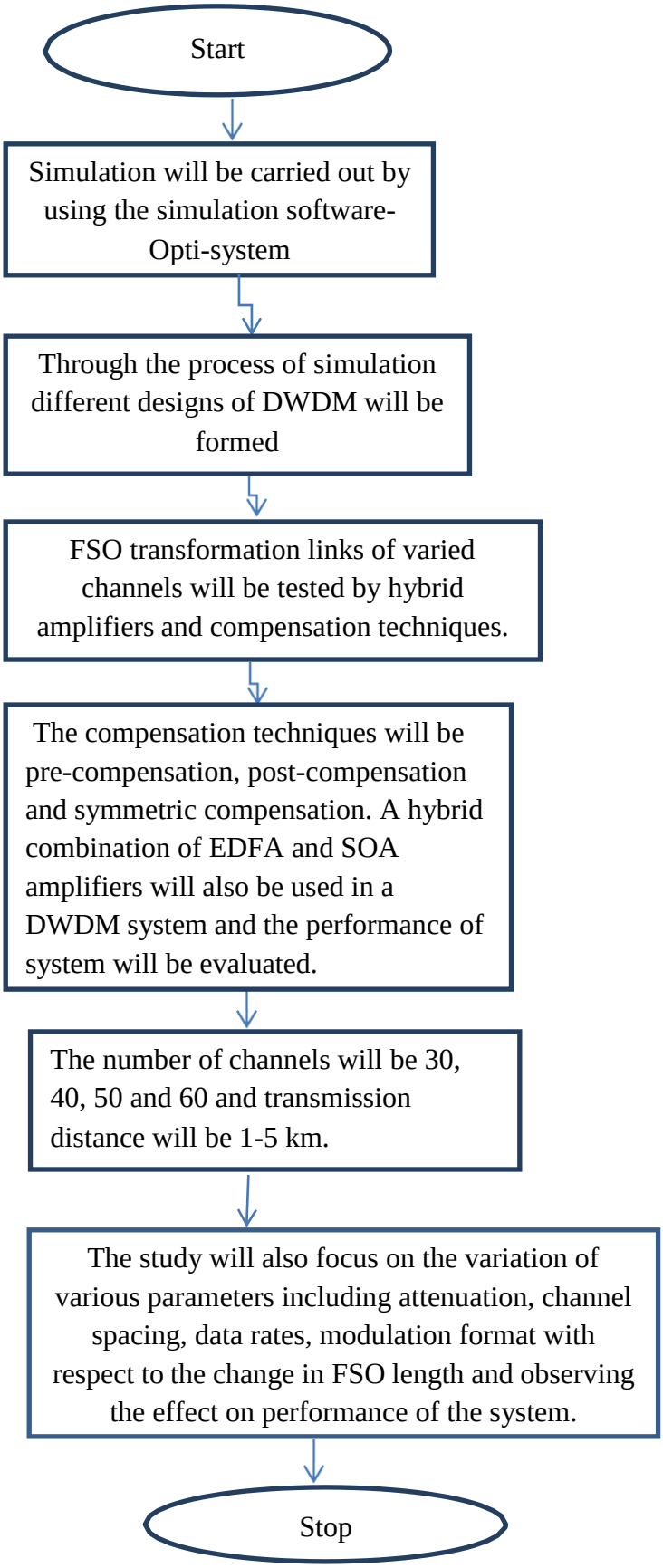
Start
Simulation will be carried out by using the simulation software- Opti-system
Through the process of simulation different designs of DWDM will be formed
FSO transformation links of varied channels will be tested by hybrid amplifiers and compensation techniques.
The compensation techniques will be pre-compensation, post-compensation and symmetric compensation. A hybrid combination of EDFA and SOA amplifiers will also be used in a DWDM system and the performance of system will be evaluated.
The number of channels will be 30, 40, 50 and 60 and transmission distance will be 1-5 km.
The study will also focus on the variation of various parameters including attenuation, channel spacing, data rates, modulation format with respect to the change in FSO length and observing the effect on performance of the system.
Stop

Fig. 4.1 Flowchart for the methodology

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